BIOLOGICAL INTEGRITY WORKSHOP

MAY 13–14, 1999
SANDY, OREGON

Sea Grant Oregon
ORESU-W-99-002

LOWER COLUMBIA RIVER ESTUARY PROGRAM

BIOLOGICAL INTEGRITY WORKSHOP

MAY 13–14, 1999
SANDY, OREGON

Sea Grant
Oregon
ORESU-W-99-002

Oregon Sea Grant
Oregon State University
402 Kerr Administration Bldg.
Corvallis, OR 97331-2134
(541) 737-2716

This book was funded by the NOAA Office of Sea Grant and Extramural Programs, U.S. Department of Commerce, under grant number NA76RG0476 (project no. A/ESG-4), and by appropriations made by the Oregon State legislature. The U.S. government is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright notation that may appear hereon.

OREGON STATE UNIVERSITY

Sea Grant is a unique partnership with public and private sectors, combining research, education, and technology transfer for public service. This national network of universities meets the changing environmental and economic needs of people in our coastal, ocean, and Great Lakes regions.

Editor: Sandy Ridlington
Production: Cooper Publishing

Contents

Acknowledgments

This conference was skillfully organized by Bruce Sutherland, Lower Columbia River Estuary Program (LCREP). Other members of the conference planning team included Rick Hafele, Oregon Department of Environmental Quality; Jeremy Buck, U.S. Fish and Wildlife Service; Ian Waite, U.S. Geological Survey; John Marshall, U.S. Fish and Wildlife Service; Carl Dugger, LCREP Management Committee; Kathy Taylor, Columbia River Estuary Study Task Force; Carie Fox, Carie Fox Consultants; and Paul Heimowitz, Oregon Sea Grant. The thoughtful comments and discussion among all the conference speakers and participants were the most important factors behind the success of the conference.

Jennifer Gilden, Oregon Sea Grant, served as the main author of this summary and did an excellent job of capturing the essence of the conference. Paul Heimowitz assisted Jennifer and editor Sandy Ridlington in preparation of the final report.

Background

The Lower Columbia River Estuary Program (LCREP), one of 28 programs under the National Estuary Program, has just completed a comprehensive conservation management plan for the lower Columbia River. LCREP is dedicated to achieving and maintaining biological integrity within the lower Columbia River ecosystem. An essential component of the management plan is the development of a long-term monitoring plan to track the health of the river over time. The question of how to measure the biological integrity of the lower Columbia River is a critical part of this assessment.

The workshop, entitled Measuring Biological Integrity in the Lower Columbia River: How Do We Do It? was the first step toward answering the question of how to measure river health. The goal of the workshop was to develop an approach to monitoring biological integrity. Among the questions addressed were the following: Is biological integrity a philosophy, or is it a measurable quality? Can we identify the subsystems that constitute biological integrity? Can the subsystems be measured by a suite of indicators? If so, what would they be? Can the health of the river be described by a metric or a number of metrics?

For the purposes of the workshop, biological integrity was defined as the ability of a system to support and maintain an integrated, adaptive community of organisms with a composition and organization comparable to systems supported by natural waters in the region.

The workshop was held on May 13 and 14, 1999 at the Collins Retreat Center near Sandy, Oregon. Fifty-five people participated in at least part of the workshop. It was sponsored by LCREP and the Pacific Northwest Marine Invasive Species Team.

LCREP would like to acknowledge the members of the workshop planning team:

Bruce Sutherland, Workshop Coordinator, Lower Columbia Estuary Program

Ian Waite, U.S. Geological Survey

Paul Heimowitz, Oregon Sea Grant

Rick Hafele, Oregon Department of Environmental Quality

John Marshall, U.S. Fish and Wildlife

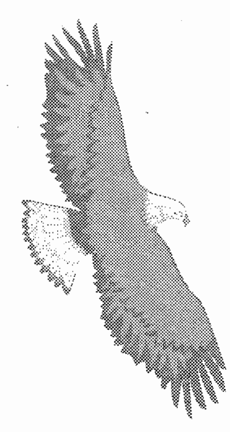
Jeremy Buck, U.S. Fish and Wildlife

Carl Dugger, Washington Environmental Council

Kathy Taylor, Columbia River Estuary Study Task Force

Carrie Fox, Facilitator

The workshop was the first step toward answering the question of how to measure river health.



Introduction

Debrah Marriott, Director of the Lower Columbia River Estuary Program

After three years, the Lower Columbia River Estuary Program (LCREP) is preparing to print its comprehensive management plan. Improving the biological integrity of the Columbia River system is LCREP's fundamental goal, and all other issues, such as fostering stewardship, raising public awareness, and overcoming managerial constraints, are a means to that end. The levels of habitat loss, toxic contaminants, and pollutants in the Columbia River indicate that much needs to be done.

Evaluating the biological integrity of the Columbia River is similar to a patient's visiting a doctor for a checkup.

This meeting will focus on understanding the scientific knowledge of the system. In its partnership with scientists, LCREP is working to create better measurement tools, make better decisions, and foster stewardship of the system. This meeting will also address the challenge of viewing the system from a holistic perspective.

Evaluating the biological integrity of the Columbia River is similar to a patient's visiting a doctor for a checkup. If the patient asks, "How am I doing, doctor?" the doctor might reply in simple terms: "You're doing fine," or "You're not doing very well." Or the doctor might send the patient to a series of specialists who would report individual test results unrelated to any cumulative statement of the patient's well-being. Alternatively, the doctor could describe the health of the patient's internal systems ("Your respiratory system is in top form, but your circulatory system is partially blocked"). The value of these and other approaches needs to be considered when examining how best to characterize the health of the Columbia River estuary.

Developing Biological Indicators in the Sacramento River

Dick Daniel, Assistant Director, CALFED Bay-Delta Project

The CALFED Bay-Delta Project began four years ago to work on conflicts associated with water development and transport in California. CALFED's geographic scope is large, and its mission requires it to interact with agencies and communities throughout the entire state. Fifteen state and federal agencies, in which almost all the regulatory and management authority in central California is vested, participate in the project. Currently, CALFED's mission is to develop a comprehensive plan to restore ecosystem health in the Sacramento River. Achieving this goal is complicated by the limited water supply, a population highly dependent on the Sacramento, numerous water quality problems, and a delicate system of levees in the Sacramento delta.

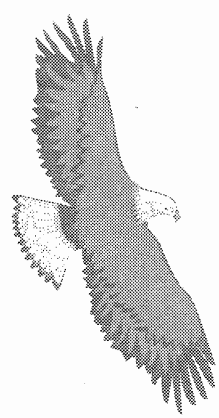
CALFED is trying to move away from the "species du jour" approach that concentrates only on popular species and to focus instead on indicators of biological integrity. Indicators are a measurable surrogate for an environmental endpoint. They are based on structural and functional attributes of an ecosystem and can be a composite of several attributes.

The following are characteristics of good indicators:

- They are ecologically relevant.
- They are sensitive to change.
- They are measurable.
- They are available.
- There is a focus on baseline data, using historic databases.
- They are based on an appropriate temporal scale such as the life cycle of a species, the hydrologic cycle, or seasonal cycles.
- They are statistically relevant.
- They can be linked to present a comprehensive portrait of the ecosystem. For example, project scientists have found that the area and duration of floodplain inundation is crosslinked to many different indicators.
- They are flexible so they can adapt to alterations in the system, disappointments in projects, and other changes.

At a CALFED-hosted workshop to discuss indicators of ecosystem health, participants suggested some new measurements, such as the percentage of surface area covered by asphalt. A second workshop focused on stressors in the system as well as attributes that were healthy, that should stay healthy, and that should be monitored.

CALFED is trying to move away from the "species du jour" approach that concentrates only on popular species.



Participants concluded that three different levels of indicators were needed:

1. Essential ecological indicators

2. Management-level indicators

3. Ecosystem health indicators

Participants concluded that three different levels of indicators were needed:

1. Essential ecological indicators. Essential ecological indicators communicate progress to the public and to funding agencies and educate the public about the importance of ecological indicators in general. Indicators of this sort would be released at a press event in an easily understandable way—for example, the "white sneaker index" (the depth at which a person's white sneakers are still visible) used in the Chesapeake Bay.
2. Management-level indicators. Management-level indicators focus on management and policy decision makers. There is much scientific uncertainty, and CALFED's stakeholders are critical because they aren't hearing definitive scientific answers. So we've adopted an adaptive management policy: learn by doing. We use these indicators to gauge the activities we're undertaking and to see whether we need to change course or accelerate the rate at which we're doing them.
3. Ecosystem health indicators. Ecosystem health indicators, which involve many habitat types and ecological attributes, are targeted at scientists. These indicators shift more slowly than others, but are more stable and long lasting.

Framework for Developing Indicators

Within the Sacramento system are upland mountain river and floodplain ecosystems, alluvial river and floodplain ecosystems, the delta ecosystem (reclaimed marsh), and San Francisco Bay. CALFED scientists found attributes of geomorphic, hydrological, biological, habitat, and community energetics within each ecosystem. Among other things, the researchers are focusing on the separation of rivers from their floodplains, the use of groundwater in the system, and the use of flow regimes and water levels as indicators. The variability of flow regimes also plays an important role. The species in these ecosystems evolved to take advantage of recurring features of hydrology, including high and low flow events, which are critical to restoring the system.

Conceptual models were used to depict cause-and-effect relationships among attributes and to shape and refine testable hypotheses regarding ecosystem structure and function. CALFED used a number of indicators:

Stressors

Stressors are primarily human-caused problems, such as water diversions, dams, mining, exotic species, overharvest, predation, and contaminants (such as body burdens of mercury).

Pressure-Related Indicators

Pressure-related indicators are linked to such stressors as contaminants and exotic species. The San Francisco Bay is one of the most stressed bodies of water in the world by exotic species.

Ecosystem State Indicators

Measured using GIS techniques, ecosystem state indicators monitor the quality, area, and extent of habitats in the system over time. Fish population indices are also a useful tool.

Response Indicators

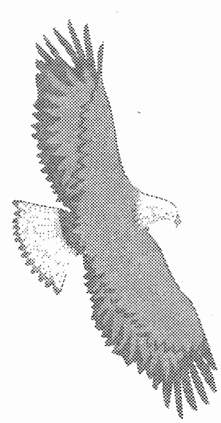
Response indicators describe management actions such as the number of exotic species control plans, expenditures on pollution abatement, and the number of diversions that have been covered with screens.

For example, in the Butte Basin area of the upper Sacramento River we tried to identify the most important indicators and determine whether they would show movement within seven years. Butte Creek is a flashy runoff stream with an endangered population of spring chinook. For the past 20 years, fewer than 1,000 spring chinook per year have returned to the creek. However, restoration efforts have been remarkably successful: this year, the spawning index was 20,000 fish. The summer minimum flow is most limiting in terms of biological productivity, and it is complicated by the agricultural community's use of the water. Indicators used in Butte Creek include annual flow regime, groundwater level adjacent to the stream (important for maintaining temperatures that allow fish to survive), and base flow. We also looked at habitat mosaic and connectivity, miles of riparian habitat, community energetics, and the length of river obstructed by manmade barriers.

Sometimes indicators move in a negative direction. When this happens, you must ask whether they were appropriate to begin with. Was the conceptual model appropriate? Is there an unknown or new stressor? Are there unanticipated interactions between stressors? Part of CALFED's budget is allocated to monitoring indicators. Indicators will be reviewed constantly in annual workshops.

If indicators are not associated with specific management plans, then I recommend focusing on ecosystem integrity, monitoring, and performance measures. Performance measures are necessary because people who are affected by the projects and those who pay for them want some degree of certainty that actions are having a positive effect. CALFED is fortunate is this respect because we work with voluntary participants whose financial responsibility for the projects is limited, and thus they demand less than absolute certainty.

The species in these ecosystems evolved to take advantage of recurring features of hydrology.



Developing Biological Indicators in the Lower Columbia River Basin

Steven Ellis, EVS Environmental Consultants; Project Director, Bi-State Water Quality Study, now working with Willamette River bioindicators.

The Oregon Department of Environmental Quality (DEQ) has been developing bioindicators in the Willamette River Basin, which supports 80% of Oregon's human population and is the largest tributary of the lower Columbia. The DEQ has looked at trophic levels, benthic invertebrates, and other indicators, but this talk will focus on the advantages of using fish as a biological indicator. Fish are always in the system. They assimilate chemical, physical, and biological changes; they're relatively easy to measure; and they have long lifespans and large ranges. In addition, there's a good database of information on fish. Sampling can occur over a long period of time, the taxonomy is well understood, and the distribution and tolerance to environmental stresses is well documented. Also, the public understands fish.

We used three different indices for this study: the multimetric fish index, a fish autopsy-based index, and a histopathological fish index.

The public understands fish.

Multimetric Fish Index

The multimetric fish index applied in the Willamette is the Index of Biotic Integrity, developed by Karr in 1981.[1] The most widely applied multimetric index, it has been used in and adapted for various regions. Multimetric techniques require measuring and scoring a number of characteristics. Species composition, trophic composition, and measures of abundance and condition of fish were the major categories used in the Willamette. In this system, they were rated 5 (good), 3, or 1 (poor), and the scores were then summed. We have 13 metrics, meaning that ideal conditions receive a score of 65 (13 x 5).

To use the multimetric fish index to determine system health, you need to understand what constitutes a significant change in scores, for some variability is natural (for example, different flow regimes caused by precipitation). On average, scores could vary 10 points (out of a total possible score of 65) between years. We found that five metrics—percent salmonids, percent cottid species, percent insectivores, number of native species, and number of individuals—explained over 90% of the change.

I recommend a multimetric approach where suitable metrics are evaluated, the river is divided into appropriate study regions, and fish collection techniques are modified according to context. For example, in the Columbia, electroshocking is not going to characterize accurately which

[1] J. R. Karr, 1981, Assessment of biotic integrity using fish communities, *Fisheries* 6:21–27.

fish are present. Trawling or gillnetting would probably be more suitable.

Fish Autopsy-Based Index

The fish autopsy-based index, developed by Goede in the 1980s to assess rainbow trout, involves looking at external fish features such as eyes, fins, and scales; internal organs; and blood parameters. Goede has created a picture atlas that allows you to score the health of each fish.[2] Results are expressed as a percentage of fish that exhibit deviations from normal.

To look at the percent of abnormalities in the Willamette Basin, we focused on northern pikeminnow (squawfish) and largescale sucker. The DEQ was interested in linking this index to local effects, but without information about movement of the target species, such correlation is not possible. Local effects might not be representative if fish migrate far to spawn.

Local effects might not be representative if fish migrate far to spawn.

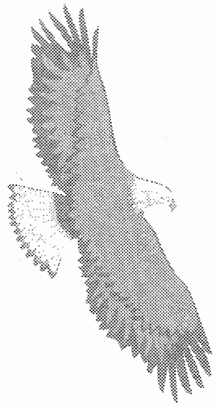
If modified for selected species, this index might be applicable for some fish in the lower Columbia. The scoring system is based on appearance, which varies among species. The subjective nature of the scoring might also be a concern, especially if the research team changes. Moreover, you must collect a large amount of data to understand the range of parameters.

Histopathological Fish Index

The histopathological fish index, which looks at vertebral deformities in juvenile fish, is probably the most successful index we used. It has been applied to marine and freshwater fish and was used in the Willamette Basin in 1992, 1993, 1994, and 1998. This is an uncomplicated, low-cost index. We already understand how fish are affected by vertebral defects. However, a wide range of physical, chemical, and biological stressors can induce these abnormalities, and it is difficult to differentiate the causes.

We collected juvenile (less than one year old) northern pikeminnow along the main-stem Willamette and preserved them in buffered formalin. We focused on young fish because we expected that severely deformed adult fish would be limited through predation and because we wanted to see local effects. We do not believe that juvenile squawfish move far before spawning—probably fewer than two to three miles. We randomly selected 75 to 200 fish from each site. The fish were bleached and their bones and cartilage were stained to allow us to see them more easily. We looked at them under a microscope and tabulated the number of fish with deformities. Fish with scoliosis or fused or deformed vertebrae were classified as exhibiting vertebral defects. Values less than 5% can be attributed to background levels of mutation.

[2] R. W. Goede, 1993, Fish health/condition assessment procedures, unpublished, Utah Division of Wildlife Resources, Fisheries Experiment Station.



Findings

We selected only two sites in the mid-Willamette, and in both places the fish had four times more skeletal deformities than in the background level. We conducted a second study to provide additional spatial characterization of the incidence of vertebral abnormalities; to examine spatial patterns relative to point-source discharges; to compare our data with previous surveys; and to look at species besides northern pikeminnow. We also conducted an upstream-downstream comparison of point-source discharges.

We will do follow-up experiments looking at rainbow trout embryo development, a sensitive life stage. We will fertilize embryos and put them in exposure cylinders that will be anchored in the Willamette. The cylinders will be removed from the river before the embryos hatch. The eggs will be brought into a lab and raised to larval stage. Comparing our results to a control group, we'll measure the percentage of hatching survival and percentage of skeletal deformities.

Among the many potential causes of juvenile fish deformities are heavy metals, organophosphates, and other organic compounds.

Among the many potential causes of juvenile fish deformities are heavy metals, organophosphates, and other organic compounds. Apart from chemical uptake, other stressors include temperature, low dissolved oxygen, vitamin deficiencies, and parasites.

Conclusions

I believe this monitoring technique would work well in the lower Columbia if modified for sturgeon and chinook. In summary, I would recommend considering fish indicators for the Columbia River, particularly a multimetric fish index and species-specific indicators for particular areas of concern.

Experiences Attempting to Measure Biological Integrity on the Fraser River

Colin Levings, Department of Fisheries and Oceans, Canada

The Fraser River watershed is about the size of Great Britain. The flow regime is similar to what the Columbia used to be like—high runoff in the spring due to snowmelt and ice, and high runoff in the fall due to rain. The mouth of the estuary, however, is very different from the Columbia's mouth. Vancouver, B.C., home to approximately 1.5 million people, is located there. Most human activity that occurs on the river occurs at the mouth, and most of the habitat alteration is the result of diking and urbanization. There are major drying banks through the Strait of Georgia, and 14,000 hectares of sand flats. The main-stem Fraser River is undammed, although there are small dams throughout the system and one tributary is dammed. The watershed's interior plateau is dry, whereas the lower subbasins are wet. There are fewer exotic species in the Fraser than in the Columbia. Exotic species in the system include brown bullhead, carp, and pumpkinseed.

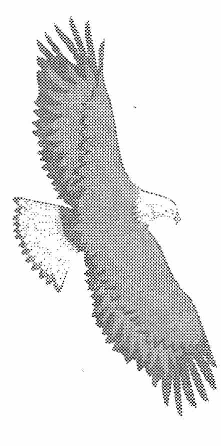
Research on the Fraser River has focused on the importance of the food web for feeding juvenile chinook salmon. Research has emphasized the plants, insects, and invertebrates that compose salmon's food web. Indicators used include above-ground vegetative biomass (the average biomass of the undisturbed marsh in the estuary); the composition of fish, plant, and invertebrate species; decomposition patterns of exotic plant species; bioaccumulation of contaminants; and density of total invertebrates in the marshes.

To determine what species we should use for water quality and pollution monitoring, we looked at starry flounder, chinook juveniles, and eulachon. We focused on starry flounders to estimate their home range. We needed to look at how long they stayed in an area, so we radio tagged flounders.This produced very interesting (though expensive) results.

The river is also a major sockeye production system, and to look at sockeye fry we sampled transects across the reach, using surface trawling. It was a labor-intensive process, but it produced interesting data.

We've also looked at zonation along the shore. Our management scheme focuses on these primary habitat types: channel, sand and mud flats, brackish march, salt marsh, riparian areas, wet meadows, and eelgrass.

Most human activity that occurs on the river occurs at the mouth, and most of the habitat alteration is the result of diking and urbanization.



Assessing Estuarine/Tidal and Freshwater Habitat Landscape Structure on the Lower Columbia River

Charles Simenstad, University of Washington School of Fisheries

It's often the composition, distribution, and organization of landscapes that regulate ecological functions.

When searching for indicators of ecosystem integrity at larger than habitat- or site-specific scales, we can organize approaches in three categories: landscape attributes (the structural elements and arrangement of the system); indicators of important landscape processes across a broad scale; and integrators of biological and ecological responses.

Although habitat area can indicate certain biological processes, it's often the composition, distribution, and organization of landscapes that regulate ecological functions. And it's difficult to identify aquatic organisms that don't integrate the landscape over various areas.

The idea of essential ecological indicators came from the concept of leading economic indicators. They can be used as report cards on ecosystem health, as they integrate a large amount of technical information. Their purpose is to describe the health of the ecosystem and ecosystem trends, to build public support, to provide accountability for progress toward restoration, and to be part of a system of indicators encompassing stresses, state, and response to management actions. Desirable essential ecological indicators capture processes at the ecosystem/landscape scale, and they are representative, accurate, and hierarchical (in other words, they depend on technical measurements).

Essential ecological indicators *must* be ecologically relevant and scientifically defensible. They *should* be integrative, general, sensitive, easy to measure or already measured, benign to measure, relevant to managers, easy to understand, valued by the public, and likely to stand the test of time. Following are four examples of essential ecological indicators:

- **Extent of habitat** describes the proportions of major habitat types to their historic proportions. What size is minimally acceptable?
- The **index of naturalness** focuses on geomorphology—the length of the river channel fish are free to migrate, the length lacking riprap, the length having natural flooding or sediment, and so on. Sediment supply is particularly germane to the Columbia and needs to be factored in.
- The **index of marsh integrity** focuses on marsh and bay health and the intertidal marsh and mudflat system (channel complexity, vegetation diversity and continuity, net accretion) and bay bathymetry (compared to historical data, measuring the net eroded area).

- The **index of riparian and wetland vegetation** focuses on the fragmentation and connectivity of vegetative communities.

Remote Sensing

In Willapa Bay we used aerial images to determine how the integrity of the estuarine community was related to habitat structure and what patterns existed. In comparing a complex system with a simple system, a definite response of the metrics to the variation in the habitat emerges. Until now, most remote sensing has not allowed a detailed enough image, but the technology is rapidly advancing and might eventually allow us to separate exotic species from natural species of plants. The ability to link tidal channel geomorphology to various habitat components can be enhanced by this sort of analysis. We used remote sensing to study the edge-to-area ratio, which is a good indicator of fish usage and sedimentation.

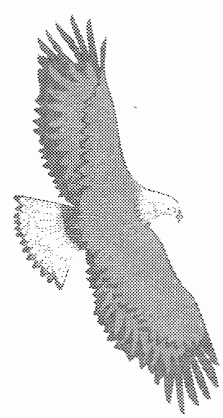
The technology is rapidly advancing and might eventually allow us to separate exotic species from natural species of plants.

We would also like to use remote sensing to look at tidal channel geomorphology, which has a strong relationship to ecosystem function. We might be able to use a network analysis or an edge-to-drainage area ratio to tell us about the loss of integrity in this system.

Several additional indicators might prove useful:

- The **large woody debris import metric.** Large woody debris has been argued to have major ecological function.
- **Productivity**, such as the proportion of marsh-derived organic matter and consumer organisms. We've used stable isotope geochemical markers to look at the sources of organic matter in Willapa Bay. The ratio of isotopes has the same fundamental signature throughout the food web. Spartina has a strong composition in mud snails and certain crabs, so the proportion of spartina microcarbons in animals and plants might be a good indicator.
- The role of **estuarine turbidity maximum**, a physical circulation trap of organic matter coming into the estuary. The leading edge of the saltwater mass is a physical trap of particles for 10 to 14 days and is a potential digester of organic matter that moves through bacteria and microbes into higher-level consumers. Turbidity and zooplankton communities are connected. In the Columbia, what does the loss of major tidal marshes and swamps mean in terms of the food web? Since 1870, detritus and phytoplankton have increased tremendously because of reservoirs and other factors, which could mean a significant change in the food web.

In an integrative system, capturing indicators of function at the landscape scale becomes very complex, especially in lower estuaries. The increased capability of remote sensing technology will help a great deal. However, the fundamental problem of finding a suitable reference still exists. There's also a need for special studies and validation of the studies being done on the Fraser River. Mapping habitat structure would be a good start.



Assessing Terrestrial Species in the Lower Columbia River

Chuck Henny, U.S. Geological Survey, Biological Research Division

I have been working with the U.S. Geological Survey to study the populations of osprey on the Willamette and Columbia Rivers, and bald eagles and river otters on the Columbia. In general, osprey populations are increasing dramatically along the Willamette River and to a lesser extent along the Columbia. Eagle populations along the Columbia are increasing, but at a much slower rate.

The species of most concern are fish or fish-eating wildlife species at the top of the food web.

Ospreys

Ospreys, first studied throughout Oregon in 1976, have become a common nesting and ecosystem indicator species along the Columbia River (river mile 31-286) and Willamette River (river mile 0-178). The Columbia River has received increased attention in recent years, partly because of declining salmon stocks and concern about bald eagles, river otter, mink, and other wildlife species associated with the river.

A wide range of toxic chemicals is found in the water, sediments, and aquatic life of these rivers. Concentrations of some organochlorine pesticides (OCs), polychlorinated biphenyls (PCBs), dioxins, and furans are potentially toxic to fish, wildlife, and humans. These toxic chemicals are lipophilic (attracted to fat molecules), becoming chemically bound to fat molecules and therefore accumulating in organisms through a process known as bioaccumulation.

Once absorbed by plankton or other organisms in the water, these organochlorine molecules become more concentrated in the bodies of organisms at higher trophic levels of the food web. The species of most concern are fish or fish-eating wildlife species at the top of the food web. Detailed studies are being conducted throughout the Columbia River system (including the Willamette River) to evaluate osprey reproduction with respect to contaminant residue patterns. In addition, this is the third year that transmitters have been attached to osprey under a cooperative program with the University of Minnesota. Ospreys nesting east of the Cascade Mountains appear to have different migration routes and different wintering localities. Information about these routes is important when evaluating contaminants in a migratory bird such as the osprey.

Columbia River Bald Eagles

As top predators in the food chain, bald eagles are sentinel species for the overall health of aquatic areas such as the lower Columbia River. In 1994 and 1995, the U.S. Fish and Wildlife Service and the Oregon Cooperative Wildlife Research Unit at Oregon State University investigated the role of contaminants in the reducing the reproduction rates of bald eagles nesting along the lower Columbia River.

Concentrations of DDE and total PCBs in the eggs of these eagles have declined since the mid-1980s. However, these contaminants, along with dioxinlike compounds, still exceeded estimated no-effect concentrations, reference concentrations, and concentrations associated with reduced productivity for bald eagles in other studies. DDE and total PCBs were not correlated to nest location along the river (river mile), suggesting that these compounds do not increase as one moves downriver.

In contrast, some dioxin, furan, and toxic equivalent (TEQ) values (representing the toxicity of all dioxinlike chemicals in the eggs) were related to river mile, which might reflect releases of the contaminants from upriver sources and their deposition in specific areas (for example, tidal flats) of the lower estuary. Dioxin, furan, and TEQ concentrations were highest at 23 older nest sites, which were located predominantly in the lower estuary below river mile 50. Productivity at newly established nest sites was much higher than productivity at older nest sites exhibiting a long history of poor reproduction. This evidence suggests that pairs at older nest sites are affected by contaminants to a greater extent than pairs at newly established sites.

Although the number of bald eagles nesting along the river is increasing, continued foraging on contaminated prey from the Columbia River and subsequent bioaccumulation of contaminants could limit future productivity of some new pairs as these chemicals accumulate in adult birds as they age.

Concentrations of DDE and total PCBs in the eggs of these eagles have declined since the mid-1980s.

River Otters

River otters are good integrators of their aquatic environments and are a useful indicator species for determining both wildlife and human chemical exposure and potential harmful effects. During the 1996–97 trapping season, 260 river otter carcasses, including 224 males, were purchased from licensed trappers from the lower Willamette and Columbia Rivers, the Puget Sound-Hood Canal area, and a reference area by the USGS Biological Resource Division in Oregon and Washington. In an earlier investigation of river otters from the lower Columbia River, reproductive organ hypoplasia (incomplete development) of young male river otters was correlated with 6 OC pesticides, 29 PCBs, 2 dioxins, and 4 furans. It is unknown, however, whether the adult male reproductive organs were functioning normally. The goal of continuing research is to identify the contaminants most responsible for the observed reproductive organ hypoplasia in young male river otters, the occurrence of the contaminants, and the mode of action or mechanism that causes hypoplasia.

Overview of Lower Columbia River Biomonitoring Recommendations

Ian Waite, U.S. Geological Survey

A subcommittee composed of some 30 individuals worked for a year to develop the recommendations in the long-term monitoring plan. Workshop participants were provided copies of these recommendations, which represent the subcommittee's best judgment based on the information available. In some topic areas, the subcommittee ran out of time before the recommendations could be fully developed. These topic areas included habitat; the number and distribution of nonindigenous species; and nutrients, primary production, and food webs.

One aim of the workshop is to refine these coarse recommendations into a higher level of detail. For example, we need to discuss sampling design and indicators and agree on how to summarize the information for the public. Discussion groups will focus on habitat, macroinvertebrates, fish, possibly zooplankton, and nonindigenous species.

One aim of the workshop is to refine these coarse recommendations into a higher level of detail.

Panel Presentations

Habitat

Phil Kaufman, Environmental Protection Agency

In monitoring habitat processes, we can see only a "state variable"—conditions at an instant or several instants in time. These snapshots in time can be improved by the integration of various elements and the design of where measurements are taken. The various elements include the needs and conditions affecting any given organism: habitat space and the flow and velocity affecting that space; the size, spatial pattern, and stability of the substrate; habitat complexity; floodplain, riparian, and instream vegetation; anthropogenic alteration such as land use, dams, and water withdrawal; and channel, riparian, floodplain, and hyporrheic interactions. A bathymetry of the entire basin would help us understand the grand scale of habitat space and complexity. Scale is related to habitat metrics. There is a linear relationship between suitable habitat and organism numbers in small systems, but the maximum size of the organism is limited by the size of the system. Chinook and other fish are big but are not whale-sized; they are limited by the size of the system.

Zooplankton

Jeff Cordell, University of Washington

Zooplankton habitats are not well understood, but we know that several types of native and exotic zooplankton are found in the lower Columbia estuary. Reservoirs, free-flowing sections, backwater sloughs, fringing marshes, and the estuarine turbidity maximum are among the different habitat types found there. In the Sacramento/San Joaquin, the marginal habitats produce abundant zooplankton not usually found in the main stem. It would be helpful to divide the Columbia River into several sections before sampling for zooplankton.

Exotic species are increasingly important in the zooplankton realm. They can be indicators of the first introduction of exotic macroinvertebrates. For example, Asian shrimp larvae have been reported in the Chehalis, but adults have not been seen. This is because there are far more larvae than adults. In the Sacramento system, the native copepod, which used to occur year-round, has been marginalized to early in the spring. Later in the year, it is dominated by an Asian copepod. Periodicities (the amount of time zooplankton are present in a system) are important to understand.

To sample zooplankton in the estuarine turbidity maximum region of the Columbia estuary, we use a complicated pump system that sucks up large amounts of water through pipes and tubes. Researchers should consider using manageable sampling schemes.

Finally, we need to understand more about zooplankton and their subhabitats, both of which are mainly unexplored.

Exotic species are increasingly important in the zooplankton realm.

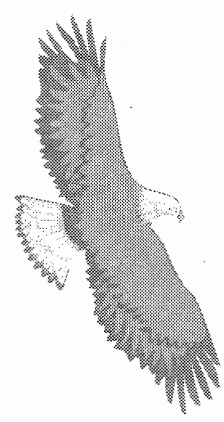
Invasive Species

Denny Lassuy, U.S. Fish and Wildlife Service

This workshop focuses on the term "integrity," or "normalcy." But what is normal? It is crucial to understand the agents of change in a system, especially those that alter the dynamics between the subsystems. Exotic species—particularly those that alter subsystems—are important agents of change. Each subset of exotic species has its own impacts. Aquatic weeds can drastically change the function of a species; phytoplankton and zooplankton can alter the food web; and macroinvertebrates can have a powerful impact. On the other hand, nonindigenous fish have often been seen as beneficial, although they have been implicated in the listings of over two-thirds of the threatened and endangered fish listed today. Whichever group you focus on, you need some sort of baseline, and not much of one exists.

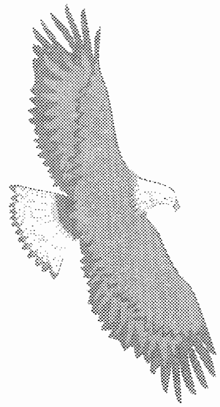
The Puget Sound rapid assessment project was a one-week expedition to sample exotic species in all types of subsystems. As far as I know, this type of effort does not exist in the lower Columbia system, although I believe the U.S. Fish and Wildlife Service and others might begin such a project this year.

Indices such as total counts and percentage of native vs. nonnative fish are useful for measuring trends. They are less effective as a correlate of impact, because it's difficult to determine which species' population might expand and damage the ecosystem and the food web. It's vital to avoid the introduction of nonnative species in the first place.



Fish

Terry Maret, U.S. Geological Survey



A simple diagram of the lower Columbia from Hiram Li's 1987 paper shows the different types of fish species from the headwaters in Idaho to the estuary. They fall into five different families: salmonids, sculpins, suckers, dace, and others. Enough species are available in the lower Columbia estuary to do an IBI. There's a good gradient of sculpins and salmonids, but fewer suckers and dace. Then there are the aliens: walleye, yellow perch, crappie, smallmouth bass, channel catfish, common carp, and American shad. The lower Columbia resembles a warm-water fishery in the Midwest, where the IBI was developed.

The Columbia River system has wide spatial variability and 8 to 10 major habitats. It's a diverse system that includes saltwater gradients, a transition area, tailwaters, and the reach above the dams—including the Hanford Reach, which is possibly the best reference in the area.

In sample design, it's important to acquire representative samples from the predominant strata and habitats. Different types of collection gear will be required. Electrofishing and seining are very helpful, as are gillnetting and possibly trawls.

In sample design, it's important to acquire representative samples from the predominant strata and habitats.

In evaluating the IBI approach, I recommend looking at the existing data and determining whether historic data can be used, coordinating with other ongoing assessments, doing a reconnaissance before designing the program, and designing your sampling based on reconnaissance and identified habitat changes. Try a stratified random design, identifying segments of 50 K or more, dividing them into reaches of about 2 K, and randomly selecting reaches to sample. To minimize seasonality, sample the reaches in summer, but look at a subset in different seasons. Sample some reaches every year.

For larger rivers, like the Columbia, I would recommend focusing on nearshore areas. Because cover and food are there, that's where fish spend a major part of their life cycles. Traditional sampling gear is most effective in nearshore areas. This fish assemblage will be responsive to habitat change, such as flow regulation. Backwater and slough areas might be a small percentage of the space in the lower river, but they are usually very productive.

Some types of analysis with which to evaluate biotic integrity are presence/absence, relative abundance, size, conditions, catch-per-unit effort, and metrics such as percent of native cold water species, number of sensitive species, percent tolerant aliens, percent anomalies, number of salmonid age classes, percent riverine habitat specialists, percent riverine-dependent species (anadromous salmonids), and percent macrohabitat generalists (like carp).

In Western streams we see the native cold-water species assemblage in high-quality waters and the nonnative cold water species that still require high water quality. With decreasing water quality, we see few or no cold-water species, and tolerant and introduced species.

Macroinvertebrates

Dr. Mark Munn, U.S. Geological Survey

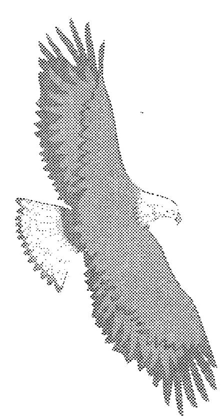
When studying benthic invertebrates, stratify the habitats you sample. Benthic communities depend on the kind of habitat in which they're found. Most of our benthic communities are based on riffles and small, shallow streams. It's difficult to find places that can be used as references, but it is also necessary to have variability in reference samples. On the Columbia, the main-stem freshwater is sand and has low diversity. I don't know whether I'd spend a lot of money on such a physically unstable area.

Select sensitive indicator species. Mayflies, stoneflies, and caddis flies have been successfully used as indicators. Consider which are sensitive and which are tolerant.

Regarding indicator habitat, in the upper Columbia River, focus on trends in high-diversity habitat. Don't try to monitor everything; instead, pick a few highly diverse habitat areas that you are familiar with.

Many benthic studies are flawed because they are too simplistic—they limit themselves to one or two measures, such as total abundance. Consider alternative ways to analyze data. Is the problem a large-scale land use issue or a small-scale contaminant issue? Be aware of the different tools available.

Benthic communities depend on the kind of habitat in which they're found.



Panel Discussion

Q. What are some concerns in using benthic organisms or zooplankton for assessing lower river regions?

A. Both are subject to invasion by dynamic exotic species. Zooplankton experience more seasonal variability but less long-term variability. Benthic communities are more subject than others to flooding events and large-scale climatic events such as El Niño. In Europe, scientists have examined and dated diatoms in old river channel deposits. However, because crustaceans and macroinvertebrates don't hold up as well as diatoms in sediments, there isn't as much potential for looking at them.

Q. In regard to benthic organisms, how does one construct an IBI with no references—no big river systems or historical data?

A. Most studies on IBIs on benthic invertebrates have looked at headwaters in Montana and Idaho, which have many reference streams. There is no solid, published, benthic index for large rivers. The Hanford Reach might be a reference possibility, but sediments there have likely been influenced by human actions. Using an IBI community might not be the right approach to take with benthic organisms. Some species contain only 8 to 12 taxa, so if you lose 1 or 2 taxa you've lost considerable variability. There are indicator taxa for zooplankton in large river systems, however. In Canada, studies on ballast water exotics have focused on copepods.

Benthic communities are more subject than others to flooding events and large-scale climatic events such as El Niño.

Q. How do we determine what's native and what's nonnative? If the sediment record won't work, do we look at current distributions of species?

A. In the Columbia River, there were extensive studies on invertebrates in 1979–1980. Genetic work can be done to learn about species introduced before that time. With fisheries, historic familiarity provides a baseline.

Q. Some members of the public feel that if there are more species in an ecosystem, then the ecosystem is more diverse—period. They don't recognize the difference between native and nonnative species and their relationship with biodiversity. Do we agree that we're focusing on the diversity of native species?

A. The introduced cold-water trout species are highly desirable. You could exclude them from an IBI, but don't downgrade the resource because it has an introduced sensitive species. To do so would also be politically unpopular. Public education on these issues is needed. Some people believe that the cleaner a body of water, the higher its diversity, and this is commonly the case with macroinvertebrates. However, sometimes highly impacted sites have more species. That's the advantage of choosing an indicator species that people relate to, like a particular fish. However, if your indicator is an introduced species like carp, the public will focus on the benefits of healthy carp.

Q. Does chemical contamination deserve more attention?

A. Yes, although nonnative species are cited almost twice as often as contaminants as a factor in ESA listings. People are more concerned about contaminants than about other factors. Even if the overall impact of chemical contamination is less, to the public it's a tremendous factor.

Q. Where is the best place to work on a benthic index?

A. The freshwater part of the Columbia River is mostly sand. Collections undertaken there have included oligochaetes and chironomids, some of which are indicator species. These collections could be used as a baseline. Some overlooked taxa such as native bivalves can also be useful indicators. In doing a benthic index, however, it might be more useful to focus on the backwaters and their habitats. Overall, it might be better to study the benthic communities in the estuary.

Some overlooked taxa such as native bivalves can also be useful indicators.

Q. How about oligochaetes?

A. In studying oligochaetes you get into issues of cost and expertise. Some people are having good luck with them, but we prefer not to use them.

Q. If I have $100,000 and two grad students to develop an index for biological integrity on the lower Columbia River, what level do I look at and where do I look?

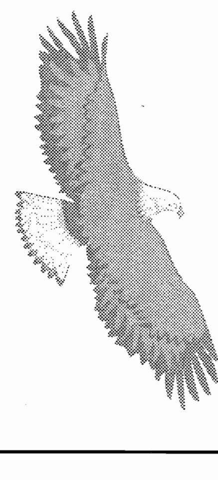
A. An IBI to me is a total fish assemblage assessment. I would suggest looking at nearshore zones and establishing a standard length and time to standardize the collections for the various habitat types. Do a different IBI for different strata—channel margin, backwater slough, side channel, and so on. Keep the data separate for each habitat and combine it for an overall reach assessment.

Q. Should I focus on fish at the expense of zooplankton or macroinvertebrates?

A. Review how the IBI is designed. It takes one habitat or one group of taxa at a time and uses it as a broad indicator. It doesn't necessarily require crossing all habitats. For example, you could sample riffles in different areas.

Q. As part of the bistate program, the region was divided into different regions and segments. Where are you going to look? You have to pick your habitat type and connection to the land use, and each area will be in a separate segment.

A. You could take a broad spectrum of backwater slough regions, but this wouldn't work well when crossing into different habitat types. In the Willamette, just selecting the sites took an entire year.



Breakout Group Discussions

To answer a series of questions, workshop participants were asked to break into three subgroups that focused on habitat, fish, and invertebrates. The working groups discussed the following questions:

What needs to be sampled to assess these subsystems?

What are the purposes and goals of the assessment?

What assessment approach is needed for these subsystems?

How do these individual assessments relate to assessing biological integrity in the Columbia River as a whole?

What needs to be sampled to assess these subsystems?

Habitat Working Group

For the habitat working group, the top priorities were to conduct a bathymetry study, a one-meter remote sensing and analysis, and a historical reconstruction data analysis and to gather information on other habitat projects taking place in the lower Columbia River. Ground truthing was also seen as an important step. The group discussed the importance of understanding the current state of Columbia River habitat and habitat loss, and the importance of communicating this information to the public.

The top priorities were to conduct a bathymetry study, a one-meter remote sensing and analysis, and a historical reconstruction data analysis.

Understanding the aerial proportion of significant habitat types would allow for effective sampling. Understanding the extent and change in wetlands species composition was seen as particularly important, although defining the extent of wetlands was a problem. Wetlands need to be classified according to the Cowardin classification, at the least. The Nature Conservancy has designed a potentially useful 250-type classification system for wetlands.

The group felt that channel configuration and bottom composition required further study using GIS, landsat, or bathymetry. There is a need for geomorphic classification based on tidal and sediment regimes. It would also be helpful to know the contribution of large wood in the system.

The habitat group generated a long list of topics that would benefit from further study. These topics include plant community composition; annual streamflow variation; fish passage; water quality; the food web; wildlife species, abundance, and use of habitat; habitat restoration opportunities; the effect of rain-on-snow zones; degree of urbanization; and critical indicator habitats.

Fish Working Group

The fish working group decided to look at an entire fish assemblage in order to develop an IBI. As a first step, researchers should review existing data and historical anecdotal data on fish in the lower Columbia. Techniques for identifying the fish assemblage could include electrofishing, trawling, and seining. The group discussed how effective and relevant these methods are for various habitats and discussed creating a matrix of techniques and various habitat types. There are inherent limitations and biases to certain methods.

The group recommended doing pilot studies before developing a monitoring program. Even with an IBI approach, it might not be possible to find good reference sites. Hanford Reach might not be a good reference site for some metrics. The group came up with nine priority habitats: (1) backwater sloughs, (2) shallow tidal areas, (3) highly urbanized reaches, (4) confluences with tributaries, areas with (5) forested and (6) unforested shorelines for comparisons, (7) the tailwater of Bonneville Dam, (8) areas with functioning floodplains, and (9) deep channel habitats. IBI methodologies would be used in similar habitat types. Fish metrics would have a different scale than habitat and other indices.

The group also talked about public opinion in relation to exotic species. For example, if the public values an exotic fish, does the presence of the fish deserve a negative or positive score?

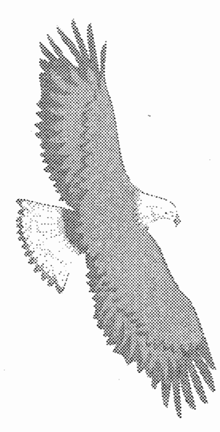
If the public values an exotic fish, does the presence of the fish deserve a negative or positive score?

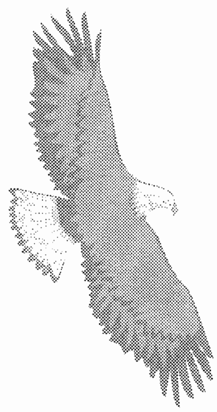
This question led to a philosophical discussion on the objectives of the project as a whole. Is the project trying to achieve a precontact river? One of the goals of the monitoring plan is to detect changes in the lower Columbia River and relate them to different management actions.

Invertebrate Working Group

The invertebrate working group focused on benthic invertebrates, zooplankton, algae, and phytoplankton. As a first step, the invertebrate working group felt that past studies and data should be analyzed. Then they recommended identifying key habitats and sampling them in a short, qualitative survey. More detailed quantitative studies could then be conducted on a subset of these habitats. Sampling methods and intensity would vary by different habitat types. Frequency could be tied to an index period based, for example, on when fish are present. The group felt it would be most effective to sample more frequently at first (for example, every month for a year) and drop back to less frequent sampling. A long-term sampling program would look at trends over time, establishing long-term sites and indicators. The group recommended resampling historically studied sites, using the same methods originally used. In terms of productivity and nutrient cycling, they recommended looking at core samples to see how cycling and sources have changed over time due to dams, flow regimes, and floodplain changes. They also recommended monitoring the work being done on levee setbacks.

The group discussed what stressors they were trying to evaluate. They also considered how the work would be funded and the need for public and political support.





Common concerns among the three groups

The three groups agreed on the importance of examining existing data and projects and being clearer about the difference between measuring the quality and quantity of a species. They agreed on the importance of nonnative species, interrelationships among subsystems, and finding suitable reference conditions. Because the fish and macroinvertebrate researchers have many commonalities regarding habitat, they might consider using the same boundaries. Other areas that were not covered by the groups included wildlife, bacteria and pathogens, contaminants, ecosystem processes, decomposition and nutrient cycling, institutional constraints, human uses and human health, restoring salmon fisheries, and salmon restoration activities throughout the basin.

What are the purposes and goals of the assessment?

The three groups agreed on the importance of examining existing data and projects and being clearer about the difference between measuring the quality and quantity of a species.

Habitat Working Group

The habitat group focused on establishing baselines, identifying trends and current status, measuring change, communicating with the public, and aiding resource management. It was concerned with relating indicators of change to natural variability. It would like to create a template to explain what is happening in other systems and explain how the system works physically and chemically. It stressed the importance of communicating successes to the public; developing a publicly accessible, perceptual model of how the river works; and helping the public see the balance between the sacrifices they make and the gains they receive from a healthier ecosystem.

Fish Working Group

The fish group supported establishing a baseline, determining the trends and status of the fisheries, measuring the response to change, and putting this change in a context the public can understand and access (including, but not limited to, a Web site). This group's aim is to develop predictive tools to aid resource management in decision making.

Invertebrate Working Group

Like the other two working groups, the invertebrate group was concerned with establishing baselines and determining the status and trends of the invertebrates. In addition, it called for identifying major stressors that affect the subsystem (the benthic and water column invertebrates and algae), identifying problems, and assessing the health of the lower trophic levels, which provide key support for higher trophic species like fish. These lower trophic levels also provide an early warning of changes in the food web or system.

What assessment approach is needed for these subsystems?

Habitat Working Group

The habitat group would like to develop a cumulative biological integrity index (BII) (not Karr's IBI), based on absolute technical data that summarizes a relative (percentage of target or baseline) cumulative index. This BII would be hierarchical, but would be transformed into relative indices where each component (subsystem) is weighted equally and the total cumulative BII is the sum of these parts. These parts would be presented to the public as a system, upstream to downstream, in which all levels of the data would be accessible. The Columbia would be divided into four reaches, based on data from remote sensing and other factors.

The habitat group recommended a reconnaissance survey of habitats, which would be a high-priority, special study to be done before the monitoring of habitat and biological integrity could begin. Special studies are areas where ongoing studies can be integrated or where an important gap exists in the data. If special studies must be done before monitoring begins, they should be identified early on.

If special studies must be done before monitoring begins, they should be identified early on.

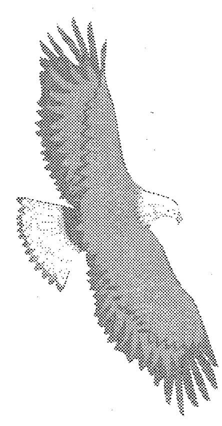
Fish Working Group

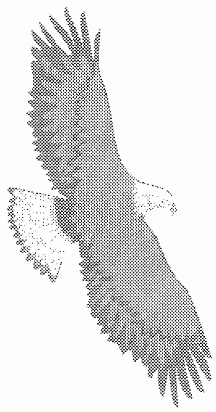
Using the Willamette IBI as a starting point, the fish group would assess the results as a matrix of fish assemblages/ abundance. Using various metrics of stressors (such as number of exotics, percent of skeletal abnormalities, and contaminants), they would equate these in a cumulative grading. They felt it was important not to report the final cumulative score by itself; the grading must have supporting documents so the public can understand the importance of differentiating native and nonnative fish, the stressors, and so on. The participants felt it would be difficult to explain why the score was high if there were no native species present. By itself, the number would not be accurate, given the presence of nonnative fish. The IBI could be done on native species alone, but the public might not understand why nonnative fish were faring better than natives were.

Invertebrate Working Group

The invertebrate group would rely heavily on community structure based on habitat types or other factors. Then they would develop indices similar to a benthic or zooplankton index. Third, they would identify indicator species. With many of these groups, strong indicator species can be used to track trends. Some exotics could also be used as indicators. Using indicator species in general might be one of the easiest ways to communicate changes to the public.

Members of the invertebrate group felt they could take widely varying approaches to this problem, depending on how their questions were framed. They will know more about the indices when they better understand the community structure. From there, they can identify indicator groups or





species. They felt that because their subject species were so sensitive, they could shape their assessment based on what others needed to know. Some special, basic studies might have to be done to establish a baseline and determine what to monitor.

How do these individual assessments relate to assessing biological integrity in the Columbia River as a whole?

Habitat Working Group

The habitat group presented a graph demonstrating its index (figure 1). The graph assumes that habitat indices are independent, but that all the subsystems capture the entire picture. The habitat index would not be driven by a particular faunal group. Rather, indices would include habitat area, connectivity, percent exotics, and other factors, so the public could see the role of each component. Each component would be related to a similar graph for fish or invertebrates so causalities could emerge. There would be a total habitat IBI composed of a cumulative macroinvertebrate index, a cumulative fish index, and other indices, each related to absolute data. The subindices would be weighted equally into their individual cumulative index (fish, habitat, and so on), and they would be open and visible so people could work back and see the data. One of these BIIs would be done for each geographic region of the system so that Portland or Longview could see how they were faring. The BIIs could be combined to form an ultimate lower Columbia River index.

Fish Working Group

The fish group felt that its assessment would provide a link to habitat quality and stressors, given the links built into the fish index. For example, the fish index is specific to habitat types. The fish metric should respond to the habitat metric. The river should be divided into a series of reaches defined by habitat, for example based on the original four reaches in the bistate studies. Those four reaches might have to be segmented further, such as into backwater areas. Chesapeake Bay, whose large system seems to have been successfully assessed, could be used as a model along with other approaches.

The basic link is the use of habitat types to develop the index.

The basic link is the use of habitat types to develop the index. The habitat index should show how the fish assemblage changes as a reflection of habitat quality—for example, that a decrease in wetlands has a given relationship to the integrity of the fish community. The fish index should support the conclusions made from habitat and stressor information.

The fish group emphasized that circularity should not be built into the index. The index should not be designed to show habitat change; rather, the initial analyses should be based on current understanding of the science, and as a

Region A

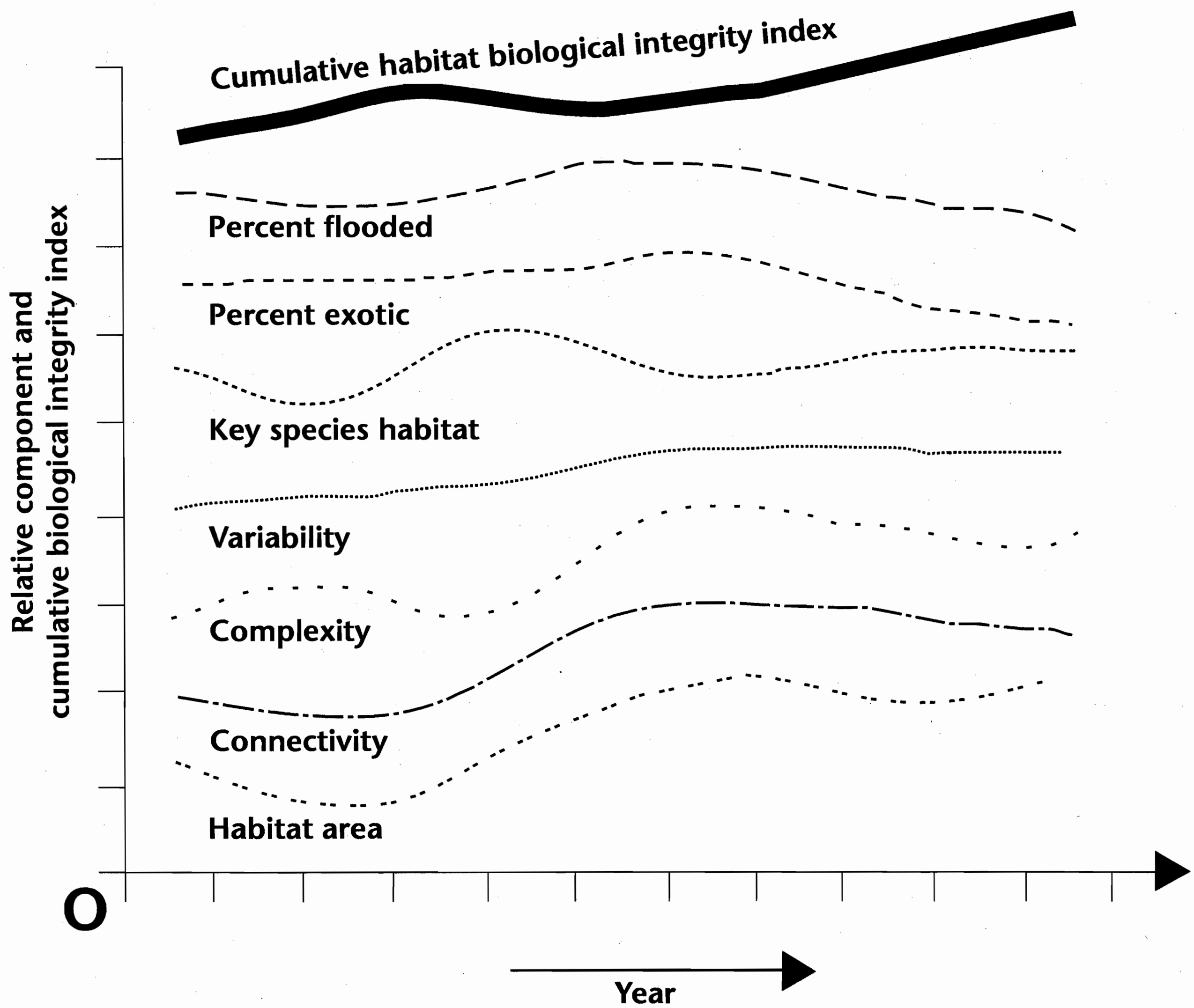
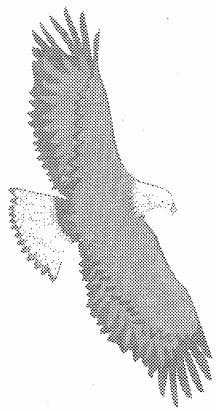


Figure 1. Sample cumulative habitat biological integrity index.

result, suitable indicators will emerge. It's important to use care in including and excluding metrics and not to focus on finding things that give us the answers we want.

Invertebrate Working Group

The invertebrate group will map degraded areas and determine the extent to which the areas are affected. Like the other groups, they need to understand Columbia River conditions in context and compared to other large systems. Much is unknown about invertebrate communities. California has datas sets as far back as 1916 that can be used for comparison. Other large systems might be using indices that can be adapted to the Columbia River. Then baselines within the system can be established, looking at within-system variance.



The invertebrate group emphasized that biological integrity means the whole system, not just salmon and eagles. Although invertebrates aren't "bumper-sticker critters," their lower trophic level feeds the higher trophic level. Invertebrates form the base of the food chain and serve as an early warning system.

The group participants expressed a desire to compare maps of degraded areas with respect to invertebrates, fish, habitat, and stressors.

Plenary Session

How can we assess biological integrity as a whole?

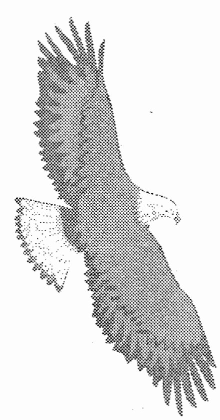
The Comprehensive Conservation Management Plan is almost in its implementation phase and will include a working group to focus on monitoring. This group will use the material generated during the current workshop. Now we must determine what is to happen during the next year. The conceptual model described in figure 1 makes sense, but to get there we need to generate indices for habitat, invertebrates, and other subsystems.

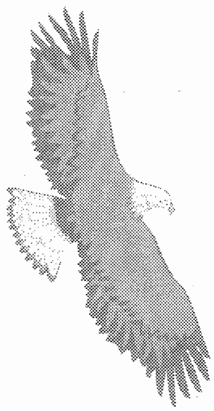
What assessment approach should be taken for biological integrity? Are there alternatives to the approach outlined in figure 1? What tests must an acceptable assessment methodology pass?

The participants felt that an acceptable assessment methodology must have the following qualities:

- Peer review
- Validity
- Relevance
- **Open data**. People must be able to see and duplicate the data used to generate the indices. The reasons for weighting metrics will be clearly explained.
- **A reference point.** The reference point must relate to baseline and historical data, when available.
- **Consistency.** There must be consistency within and among metrics, from region to region. For example, the fish subsystem and the invertebrate subsystem should have comparable components.
- **Integrity**. People must be aware of where the science ends and the policy decisions start—where science is on solid ground and where it is not. We must acknowledge uncertainty. The presentation of the data must have integrity, and the methodology must display to its user its strengths, limitations, and biases. Biointegrity should be presented in contrast to other values such as fishability, recreation, and navigability, so that it is clear what values it reflects.
- **Intellectual clarity**. Consistent layers of data should be used, and causes should not be confused with results. For example, is dredging a cause, or is it a result of economic and cultural values?
- **Sensitivity.** The assessment methods must be sensitive to the effects of stressors and other changes, and changes in stressors. Natural stressors should be considered, tracked, and distinguished from anthropogenic stressors.

The presentation of the data must have integrity, and the methodology must display to its user its strengths, limitations, and biases.





- **Public appeal.** The public must be able to understand specific indices and care enough to be willing to make the sacrifices necessary to improve them.
- **Flexibility.** The methods must be flexible enough to adapt to the development of new technology
- **Institutional memory.** The data must be managed using a common system.
- **General acceptance.** The methods must be accepted by the scientific community, managers, and the public.
- **Timeliness.** Researchers must make a timetable of periodic reassessments, as done with the consumer price index.

Stressors and responses to consider

Stressors and responses do not have a simple cause-and-effect relationship. Sometimes a stressor is a response, and vice versa. Stressors and responses should be defined in the context of a particular area. The temptation to simplify things in any given reach should be avoided, especially when stressors are located elsewhere. The following are possible stressors and responses in the lower Columbia River:

Stressors and responses do not have a simple cause-and-effect relationship.

Stressors

- Nutrients
- Sediment and turbidity
- Water quantity
- Temperature and water chemistry
- Water quality
- Exotic species

Responses

- Habitat
- Fish
- Other vertebrates
- Primary production
- Exotic species
- Zooplankton
- Benthic community
- Food web
- Aquatic, wetland, and riparian plants and algae

Concerns when choosing indicators

An assessment system is a combination of both response and stress indicators, depending on its focus. Since responses don't happen in a vacuum, stressors must be measured—and the relationship between the two is constantly changing, so the monitoring must be repeated.

The reasons for choosing specific response indicators should be carefully considered. If investigators focus too closely on a specific indicator early on, they might miss other stressors and factors.

Although this workshop has concentrated on fish, invertebrates, and habitat, the other factors listed above are also important and might be addressed in other studies.

Biological monitoring will likely show problems that wouldn't be detected by studying habitat, water temperature, or other indicators. Because nobody really knows how everything is interconnected, it's impossible to know whether we're measuring the right stressors. However, it is useful to study manageable stressors first, so we can change them. This program must remain flexible to deal with unexpected findings.

Colin Levings pointed out that when designing an assessment program for the Fraser River, scientists concluded that ecosystem integrity mimicked the historical geological, biological, and chemical processes in the system and that habitat, zooplankton abundance, and water temperature could be combined into a bigger picture of ecological processes. This conclusion directed the scientists toward the indicators they are using and helped prioritize management decisions.

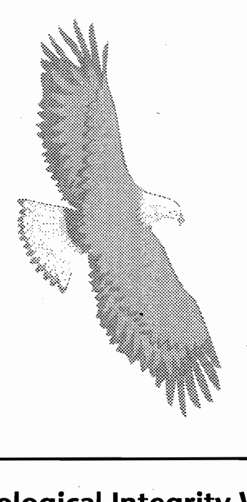
Because nobody really knows how everything is interconnected, it's impossible to know whether we're measuring the right stressors.

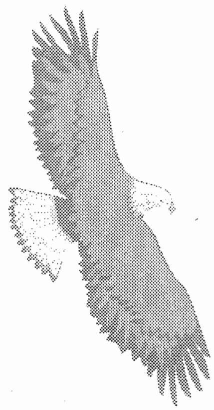
GUBIIs and SUBIIs

At this point, participants developed the terms "GUBII" (Grand Unifying Biological Integrity Index—focusing, for example, on the Columbia) and "SUBII" (System Unifying Biological Integrity Index, focusing on macroinvertebrates and other subsystems). GUBIIs are composed of SUBIIs and stressor SUBIIs. SUBIIs include habitat, vertebrates, fish, zooplankton, the basis of the food web (phytoplankton, algae, vegetation, and other organic matter), benthic invertebrates, and the individual stressors of each SUBII.

Participants then developed a rough outline for studying a generic SUBII:

1. Identify generic SUBII and its components, using best professional judgment.
2. Review existing literature and data to establish a baseline. Contact authorities already in the field.
3. Refine or develop a list of components and methodologies. Develop or adopt a conceptual model, including collecting new data. (This is an ongoing, interactive process.)
4. Establish a typology of habitats at the highest comfortable resolution.
5. Map priority habitats for the SUBII across the different strata and compare these maps with similar maps derived for other SUBIIs. (This process will begin integrating the SUBIIs and identifying more important habitats.) "Critical" habitat will vary from SUBII to SUBII. Develop or procure landscape polygons for use by SUBIIs.





6. Develop sample design.
7. Collect data.
8. Conduct data analysis.
9. Conduct peer review.

Participants felt that remote sensing should be conducted as a high-priority special study to develop a common template relevant to all SUBIIs. Much remote sensing has already been completed, especially in the main channel. High-resolution, uniform mapping from the mouth of the Columbia to Bonneville Dam would also be very useful, although it is expensive. The state of Washington is mapping all limiting factors on salmon streams. Washington has already mapped priority habitats (riparian areas and wetlands), so there are existing databases on GIS.

Participants felt that remote sensing should be conducted as a high-priority special study to develop a common template relevant to all SUBIIs.

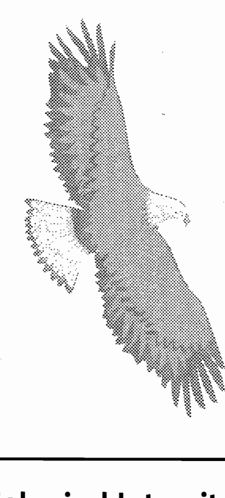
Recommendations for the Estuary Program Monitoring Strategy

- Spend one-third time gathering support for and building interest in the "Cadillac" landscape polygon remote-sensing project, which will benefit all related studies. Identify a 3- to 12-habitat strata/typology. Find out what research is already being done and what other initiatives and sources of funding exist.
- Spend one-third time with work groups, conducting a literature review. Develop a literature-review work group (focusing on individual SUBIIs) and hire a contractor or staff member to work with them to create a publication or briefing sheet that summarizes the findings. This publication could focus on habitat first, since habitat is the most complicated subject. The same work group will focus on field sampling methods, indices, components, methodology, road testing, and baselines. The work group will conduct a conference for peer review and buy-in. This habitat mapping already ties in with management actions, so seek commitment from management. Consider developing a volunteer task force to help with the literature review and field research.
- Spend one-third time working on the typology and briefing sheets listed above. Make sure to get buy-in by managers, educators, and policymakers. The publication will focus on habitat typologies, with a small map and simplified information for managers and legislators. Many of these recommendations came up 20 years ago; this briefing sheet would look at recommendations from previous plans, pointing out that they have been suggested many times. Develop a clearinghouse of data.

Final recommendations

Participants recommended that within the next 12 months, work groups should be set up to focus on individual SUBIIs. These groups will prioritize what constitutes baseline information on the SUBII and will develop field-sampling methods and design, indices, and a conceptual model. Field-testing should be undertaken, and then a "GUBII Calibration Workshop" should be organized to prepare a draft SUBII conceptual framework. The calibration workshop will allow for some peer review of this framework. Throughout this process, the public, managers, educators, and policymakers should be involved, informed, and encouraged to respond. Research should be undertaken to explore public values regarding the lower river. After 12 months, a second briefing sheet should be developed. During the second year of the project, landscape polygons should be developed or procured from outside sources.

Throughout this process, the public, managers, educators, and policymakers should be involved, informed, and encouraged to respond.



Conclusions

Participants recognized that the ecosystems of the lower Columbia River are so complex that no simple measure is possible.

The two-day workshop provided attendees an opportunity to participate in a loosely structured discussion about the merits of assessing the biological integrity of a large river system like that of the lower Columbia River. Participants discussed what such an assessment means and how it could be accomplished. The workshop was designed to set the framework for future biological monitoring in the lower Columbia River estuary. After generally agreeing that an assessment of biological integrity was a worthwhile but difficult goal to attain, participants were challenged to come to an agreement on an overall approach that met a set of agreed-upon criteria. Participants recognized that the ecosystems of the lower Columbia River are so complex that no simple measure is possible. However, they agreed almost effortlessly on the idea of a cumulative Biological Index of Integrity (BII), which would entail one index for each of (possibly) five subregions in the estuary, as well as one index of stressors for each region. The regional index (referred to tongue-in-cheek as the "Grand Universal BII," or GUBII), would be a cumulative index of the following subsystems: habitat, vertebrates, fish, zooplankton, exotic species, benthic invertebrates, and the basic food web components (phytoplankton, algae, vegetation, and other organic matter). Each of these subindices in turn would be a cumulative index of the relevant parameters within each subsystem. One of the keys to this very simple—even elegant—approach is that it allows reviewers, including the public, to "unpack" each of the indices to find the data upon which the conclusions rest.

The outcome of the workshop represents an important step forward. With agreement on where we want to go, the work of figuring out how to get there can proceed. As the Estuary Program moves into its implementation phase, it will be taking this framework and turning it into a practical tool for measuring biological integrity. The first step is to define the regions and develop a detailed inventory of all the habitats. Participants recommended using high-resolution remote sensing to accomplish this task. The group also recommended that the Estuary Program host a work group that will help develop the first of the subindices, the one for habitat. As funding becomes available, the other subindices—and their GUBII—will also be developed. The framework undoubtedly will require adjustments as scientists, managers, and educators test it.

Members of the Estuary Program are excited about the prospect and greatly appreciative of those who devoted time and energy to setting up and participating in the workshop. The level of interest is gratifying. We thank you for giving us so much to work with after this initial design workshop.

Appendix A

Attendees

Paul Adamus
Department of Fisheries and Wildlife
Oregon State University
and
Oregon Breeding Bird Atlas Project
(State Coordinator)
and
Adamus Resource Assessment, Inc.
6028 NW Burgundy Dr.
Corvallis, OR 97330
(541) 745-7092
adamusp@ucs.orst.edu

Chauncey Anderson
U.S. Geological Survey
10615 SE Cherry Blossom Dr.
Portland, OR 97216
(503) 251-3206

Craig Barfoot
U.S. Geological Survey
Biological Resources Division
Columbia River Research Lab
5501-A Cook Underwood Road
Cook, WA 98605-9717
(509) 538-2299, ext. 255

Scott Barndt
U.S. Fish and Wildlife Office
Columbia River Fisheries Program Office
9317 Highway 99, Suite I
Vancouver, WA 98665
(360) 696-7605
Scott_Barndt@fws.gov

Margaret Pilaro Barrette
Washington State Dept. of Natural Resources
Aquatic Resources
PO Box 27027
Olympia, WA 98504-7027
(360) 902-1116
(360) 902-1786
margaret.barrette@wadnr.gov

Jim Bergeron
OSU Sea Grant Extension
250 36th Street
Astoria, OR 97103
(503) 325-8573
(503) 325-7910
jim.bergeron@orst.edu

Gustavo A Bisbal
Northwest Power Planning Council
Fisheries Research Coodinator
Fish and Wildlife Division
851 SW Sixth Avenue, Suite 1100
Portland, OR 97204-1348
1 (800) 222-3355
(503) 222-5161
(503) 795-3370
gbisbal@nwppc.org
http://www.nwppc.org

Jeremy Buck
U.S. Fish and Wildlife Service
Oregon State Office
2600 SE 98th Ave, Suite 100
Portland, OR 97266
(503) 231-6179
(503) 231-6195
Jeremy_Buck@mail.fws.gov

Travis Coley
U.S. Fish and Wildlife Service
Columbia River Fisheries Program
Columbia River FPL
9317 Highway 99, Suite I
Vancouver, WA 98665
(360) 696-7605

Dr. Jeff Cordell
University of Washington
School of Fisheries
PO Box 357980
Seattle, WA 98195-7980

Tim Dalton
ODFW
4909 Third St.
Tillamook, OR 97141
(503) 842-2741
daltont@Fsl.St.Or.Us

Dick Daniels
CALFED Bay Delta Program
1416 9th Street, Room 1155
Sacramento, CA 95814

Robert Doneker
OGI
P.O. Box 91000
Portland, OR. 97291-1000
doneker@ese.ogi.edu

Doug Drake
Biomonitoring Section
DEQ
1712 SW 11th Ave.
Portland, OR 97201
(503) 229-5983
drake.doug@deq.state.or.us

Carl Dugger
Washington Environmental Council
522 18th Street
Washougal, WA 98671

Steve Ellis
EVS Environmental Consultants
200 West Mercer Street
Seattle, WA 98119

Steve Ferraro
U.S. Environmental Protection Agency
Hatfield Marine Science Center
2111 S.E. Marine Science Drive
Newport, OR 97365-5260
(541) 867-4048

Paul A. Fishman
Fishman Environmental Services
434 NW Sixth Avenue, Suite 304
Portland, Oregon 97209
(503) 224-0333
(503) 224-1851

Carie Fox
3439 NE Sandy Boulevard, Suite 149
Portland, OR 97232-1959
(503) 231-6557
(503) 736-9287
carie@foxmediation.com

Jennifer Gilden
OSU
Oregon Sea Grant
220 Waldonhall
Corvallis, OR 97330

Steven W Gray
Washington Dept. of Fish and Wildlife
2108 Grand Blvd
Vancouver, WA 98661
(360) 696-6211
grayswg@dfw.wa.gov

Rick Hafele
OR DEQ
Laboratory Division
1712 SW 11th Avenue
Portland, OR 97201
(503) 229-5983
(503) 229-6924

Russel Harding
DEQ-WQ
811 SW 6th Avenue
Portland, OR 97204

Paul Heimowitz
OSU Sea Grant Extension
200 Warner-Milne Road
Oregon City, OR 97045
(503) 722-6718

Chuck Henny
USGS-Forest and Rangeland Ecosystem Science Center
3200 SW Jefferson Way
Corvllis, OR 97331
(541) 757-4840
(541) 757-4845
hennyc@fsl.orst.edu

Philip Kaufmann
OR EPA Corvallis
200 SW 35th St.
Corvallis, OR 97333

Valerie J. Kelly
U.S. Geological Survey
Water Resources Division
10615 SE Cherry Blossom Dr.
Portland OR 97216

Janet Lamberson
U.S. Environmental Protection Agency
Hatfield Marine Science Center
2111 S.E. Marine Science Drive
Newport, OR 97365-5260
(541) 867-4043

Tony Laska
CCC/MERTS
6550 Liberty Lane
Astoria, OR 97103
(503) 338-7650
(503) 335-0567
tlaska@clatsop.cc.or.us

Denny Lassuy
U.S. Fish and Wildlife Service
911 NE 11th Avenue
Portland, OR97232
(503) 872-2763
Denny_lassuy@fws.gov

Colin Levings
Pacific Environmental Science Centre
2645 Dollarton Highway
North Vancouver, BC Canada V7H 1V2

Peter Lickwar
U.S. Fish and Wildlife
OR State Office
2600 SE 98th Avenue Suite 100
Portland, OR 97266
(503) 236-6179

Terry R. Maret
Biologist
U.S. Geological Survey
Water Resources Division, NAWQA
230 Collins Road
Boise, ID 83702
(208) 387-1328
(208) 387-1372
trmaret@usgs.gov

Debrah Marriott
Lower Columbia River National Estuary Program
811 SW 6th
Portland, OR 97204
(503) 229-5421
marriott.debrah@deq.state.or.us

John Marshall
U.S. Fish and Wildlife
Oregon State Office
2600 SE 98th Ave, Suite 100
Portland, OR 97266

Dave McAllister
ODFW
PO Box 59
Portland, OR 97207

Tom Melville
811 SW Sixth Ave.
Portland, OR 97204-1390
(503) 229-5845
DEQ, Watershed/Basin, WQ

Holly Michael
Oregon Dept. of Fish and Wildlife
17330 SE Evelyn Street
Clackamas, Or 97015
(503) 657-2000, ext. 230
(503) 657-2050
holly.b.michael@state.or.us

Dr. Mark Munn
USGS
1201 Pacific Avenue
Tacoma, WA 98402

Jennifer O'Reilly
CREST
750 Commercial Street, Room 205
Astoria, Oregon 97103
(503) 325-0435

Yangdong Pan
Environmental Science and Resources
Portland State University
Portland, OR. 97207
(503) 725-4981
(503) 725-3888
pany1@psu4.pdx.edu
http://web.pdx.edu/~pany/pan.html

Greg Pettit
Oregon Dept. of Environmental Quality
1712 SW 11th Avenue
Portland, OR 97201
(503) 229-5983
(503) 229-6924
pettit.greg@deq.state.or.us

Fred Prahl
210 Burt Hall
COAS/OSU
Corvallis, OR 97331

Lisa Randlette
State Agencies
Washington State Dept. of Natural Resources
PO Box 47027
Olympia, WA 98504
(360) 902-1085
(360) 902-1786
LRKK490@wadnr.gov

Greg Robart
Oregon Dept. of Fish and Wildlife
Columbia Region
17330 SE Evelyn Street
Clackamas OR 97015
(503) 657-2000 ext. 241
(503) 657-2050

Chris Prescott
BES
1211 SW 5th Ave., Room 800
Portland, OR 97204
(503) 823-7206
(503) 823-5565

Charles Simenstad
University of Washington
Pacific Environmental Science Centre
School of Fisheries
PO Box 357980
Seattle, WA 98195-7980
2645 Dollarton Highway
North Vancouver, BC Canada V7H 1V2

Kathy Taylor
CREST
750 Commercial Street, Room 205
Astoria, Oregon 97103
(503) 325-0435

Cal Thurlow
Clark County
8208 NW Old Orchard Dr.
Vancouver, WA 98665
(360) 573-3822

Patty Toccalino
Oregon Graduate Institute
PO Box 91000
Portland, OR 97291

Jim Turner
NMFS
525 NE Oregon St. Suite 500
Portland, OR 97232
(503) 231-6894

Rick Vining
Washington Dept. of Ecology
PO Box 47600
Olympia, WA 98504
Rvin461@acy.wa.gov

Ian Waite
U.S. Geological Survey
Habitat and Biological Integrity
10615 SE Cherry Blossom Dr
Portland, OR 97216

Christopher Walker
Bureau of Environmental Services
275 NE 197th Avenue
Portland, OR 97230
(503) 661-1732
(503) 823-5344
chrisw@bes.ci.portland.or.us

Robert Warren
CREST
750 Commercial Street, Room 205
Astoria, Oregon 97103
(503) 325-0435